Table 1. Salt Creek Basin Drainage Area (Square Miles)

Locations	Tributary Areas		Cumulative Areas for Salt Creek	
	Controlled	Total	Controlled	Total
Upstream Limit	50.1	-	50.1	177.1
Above Caldwell Branch	50.1	21.3	50.1	198.4
Caldwell Branch Confluence	8.4	15.8	58.5	214.2
Above Beal Slough	-	5.0	58.5	219.2
Beal Slough Confluence	-	12.9	58.5	232.1
Above Haines Branch	-	1.0	58.5	233.1
Haines Branch Confluence	15.1	68.1	73.6	301.2
Above Middle Creek	-	3.0	73.6	304.2
Middle Creek Confluence	46.9	101.9	120.5	406.1
Above Antelope Creek	-	3.8	120.5	409.9
Antelope Creek Confluence	5.4	12.8	125.9	422.7
Oak Creek Confluence	88.7	262.7	214.6	685.4
Above Deadman's Run	-	3.6	214.6	689.0
Deadman's Run Confluence	-	8.4	214.6	697.4
Above Little Salt Creek	-	6.2	214.6	703.6
Little Salt Creek Confluence	-	45.4	214.6	749.0

Table 1. Salt Creek Basin Drainage Area (Square Miles) (Cont'd)

Locations	Tributary Areas		Cumulative Areas for Salt Creek	
	Controlled	Total	Controlled	Total
Above Stevens Creek	-	7.6	214.6	756.6
Stevens Creek Confluence	-	51.0	214.6	807.6
Downstream Limit	-	23.0	214.6	830.6

this subbasin, but were not pertinent to the study because they are located above USACE dams. Subbasin 3 is 154 square miles. It was divided into 449 subcatchments, averaging 220 acres in size. The impervious cover in all three subbasins for urbanized areas generally ranged from 0.30 to 0.40 percent for residential and 0.50 to 0.85 percent for commercial and industrial uses.

C. Routing Model: A routing model was developed for Salt Creek from the lower end of the levee system to the downstream study limit. This is a channel distance of nearly 9 miles. The routing model was developed from conveyance curves computed from 16 surveyed river and valley cross sections. Hydrographs developed in Subbasin 3 were combined at six strategic locations along Salt Creek and input to the USACE, Missouri River Division, routing model. The seventh input hydrograph was at the upstream end of the routing model. This hydrograph was a combination of hydrographs from Oak Creek at the mouth, Salt Creek above the confluence of Oak Creek, and the intervening area below Oak Creek to the downstream end of the levee system. Because the Salt Creek levees were designed for a 1-percent event plus freeboard, a routing model was not developed for that reach. It seems likely that a storage area routing of the 500-year event may provide some attenuation, should the levees be overtopped. However, in considering the uncertainties involved in estimating the 500-year event, plus the variables that would have to be estimated in failing of the levees, it was felt that the routing would not significantly contribute additional accuracy to the study results.

D. Development of Discharge-Probability Relationships: Discharge-probability relationships were based on the 100-year discharge values computed from the hydrologic and routing models and a 0.35 standard deviation. The 50- and 10-year values developed with these models were not used. A frequency curve developed from a plot of the model values indicated a standard deviation of approximately 0.22 for most streams studied. An exception to this was a standard deviation of 0.33 produced on Salt Creek above the upstream end of the levees to near Roca. A review was made of results from a regional study of eastern Nebraska streams analyzed in a previous study. The standard deviations from eight representative streams of that study indicated an average value of 0.42. Standard deviations resulting from analyses of stream flood records for Salt Creek at Roca (No. 06803000), Lincoln (No. 06803500), and Greenwood (No. 06803555) were 0.447, 0.486, and 0.538, respectively. The periods of record used were 15, 11, and 27 years, respectively (Reference 13). The record at Roca and Lincoln does not include the period prior to the construction of the Salt Creek dams. Based on the above data, the 0.35 standard deviation was selected for determining the slope of the discharge-probability curves in the Salt Creek basin.

E. Rainfall: National Oceanic and Atmospheric Administration Technical Memorandum NWS HYDRO-35 (Reference 21) was used to select the 1-hour rainfall values for the 100-, 50-, and 10-year events. U.S. Weather Bureau Technical Paper No. 40 (Reference 22) was used for the 6-hour values. The 500-year event was determined from an extrapolation of a line drawn through the plotted 10-, 50-, and 100-year events. Maximum 1-hour values for the 500-, 100, 50-, and 10-year events are 4.60, 3.75, 3.37, and 2.51 inches. The maximum 6-hour values are 6.25, 5.20, 4.75, and 3.55 inches, respectively. These values were adjusted for basin size and shape. The Standard Project Storm breakdown-distribution procedure outlined in "Civil Works Engineering" was used (Reference 23). The 1-hour rainfall was divided into 12 5-minute values, and the 6-hour into 12 30-minute values.

F. Losses: A soil infiltration rate of 0.20 inch per hour was used for the pervious areas in the hydrologic model. Surface storage values for the pervious and impervious areas remained unchanged from the default values in the SWMM program. The Manning's "n" coefficient used for channel and overbank conditions generally ranged from 0.03 to 0.10.

Stevens Creek was analyzed by the NRCS as part of a watershed work plan. NRCS Technical Realease (TR-20), "Project Formulation – Hydrology" (Reference 24), was used in the analyses. The TR-20 program uses basin physical characteristics, rainfall, and soil and cover conditions, as related to the potential abstraction as parameters. These parameters were estimated by experienced NRCS personnel. The discharges used in this Flood Insurance Study were the "without project values," because no reservoirs have met the criteria for adequate progress to be considered in these analyses.

The discharges for Salt Creek, Oak Creek, and Stevens Creek indicate attenuation of the flood peaks due to overbank storage. Also of note is the effect of basin shape on flood peaks. The Oak Creek Basin is very long and slender due to the effective reduction in the drainage area afforded by Branched Oak Dam. This effect tends to accentuate the flood peak in relation to the upstream drainage area of Salt Creek, which is highly controlled by the Federal flood control dams.

The NRCS, Water Resources Division, was in the midst of performing a watershed work plan for the Upper Little Nemaha River basin at time that the original study was being prepared for the Village of Bennet. Therefore, the NRCS furnished discharges for the 10-, 50-, 100-, and 500-year flood flow frequencies as determined with the aid of the TR-20 computer program (Reference 24). The discharges as determined by the NRCS were compared with previously recorded maximum peak discharges. Reasonable agreement was found between the 100-year peak flows and those experienced in nearby watersheds. Therefore, the flood flow frequencies determined by the NRCS were considered valid for use in the original Flood Insurance Study for the Village of Bennet (Reference 25).

There are no gage stations on Middle Branch Big Nemaha River. There are two USGS long-term gaging stations between the Village of Firth and the mouth of the Big Nemaha River at the Missouri River. Station No. 06814500 (26 years of record) is on North Fork Big Nemaha River at Humbolt, 59.04 miles below the State Highway 341 bridge at Firth. This station has a drainage area of 548 square miles and is located 36.73 miles above the Missouri River. The flood-frequency relationships for this station for the 10-, 50-, and 100-year discharge are 40,500, 64,000, and 77,000 cfs, respectively. Station No. 06815000 (34 years of record) is on the Big Nemaha River at Falls City, 82.03 miles below the State Highway 341 bridge at Firth. This station has a drainage area of 1,340 square miles and is located 13.74 miles above its confluence with the Missouri River. The discharge-frequency relationships for this station for the 10-, 50-, and 100-year floods are 47,000, 69,000, and 78,000 cfs, respectively. From a plot of discharge-versus-drainage area, it is evident that the stations on the Big Nemaha River are too far downstream to be of use in this analysis.

The NRCS has computed discharges for flood flow frequencies using TR-20 and hand calculations (Reference 24) up to the 100-year event as part of their watershed work plan for the Upper Big Nemaha watershed (Reference 14). The 500-year discharges were determined through extrapolation.

Comparing the discharge frequency from the NRCS work plan with the USGS regionalized equations, excellent agreement is found for the 100-year flood frequency (Reference 26). Considering the standardized methods used by the NRCS versus the large-scale regional

relationships for developing and routing hydrographs at specific sites developed by the USGS, the NRCS discharge-frequency relationship will be used for this study.

For Hickman Branch and Hickman Branch Tributary, peak discharges were obtained using the Omaha Hydrograph Method as found in the Omaha Stormwater Management Design Manual (Reference 27).

USGS Stream Gage No. 06801340 on Hickman Branch was monitored from 1956 to 1961. The peak discharge recorded during this period was 12,800 cfs on July 10, 1958. Construction of two flood control dams above Hickman has significantly reduced the contributing drainage area of Hickman Branch. The following table indicates the controlled drainage area values for the above-mentioned dams.

Flooding Source and Location	Controlled Drainage Area (square miles)	Total Drainage Area (square miles)
Wagon Train Lake		
At Dam No. 8	15.6	15.6
At Dam No. 9	9.7	9.7
Hickman Branch		
At USGS Gage No. 06801340	15.6	43.7
At downstream corporate limit	25.3	53.4

The USACE was responsible for both design and construction of Dam Nos. 8 and 9. The structures are designed to withstand the probable maximum precipitation. At the 100-year flood stage, contributing discharge from these dams is minimal. Therefore, a contributing drainage area of 28.1 square miles was used to obtain peak discharges using the Omaha Hydrograph Method.

Two sets of discharge values were considered for Oak Creek and North Oak Creek. One set does not reflect the effects of the Federal flood control reservoirs or the PL-566 reservoirs designed by the NRCS. These discharges are based on a regional statistical analysis performed by the USGS (Reference 26). The parameters in the USGS regression equations are contributing drainage area, main channel length, and normal daily maximum March temperature.

The second set of discharges, developed by the USACE using the Environmental Protection Agency SWMM computer model (Reference 17), considers the flood flow reduction afforded by the aforementioned dams. The model considers both quantity and quality aspects of the runoff treatment process. Only the quantity aspect was modeled for this study. The model does this by "accounting of rainfall, infiltration, detention, overland flow, and gutter flow" (Reference 17). The sources of input data for the model are rainfall (Reference 21); contributing drainage area from USGS quadrangle mapping (Reference 28); stage-storage-discharge data from NRCS dams (Reference 29); infiltration rates from the Missouri River Basin Comprehensive Framework Study (Reference 30); and natural and improved basin characteristics and land use from aerial photo interpretation and field reconnaissance. These regulated discharge values for Oak Creek and North Oak Creek were adopted for the purposes of this Flood Insurance Study.

The discharge values are observed to decrease from the upstream study limits downstream to the confluence with Oak Creek. This is a result of the flattening and widening of the floodplain in the area of the confluence with Oak Creek. The discharge values increase again downstream on Oak Creek near West Mill Road as the floodplain narrows.

For Ash Hollow Ditch, the discharge values were computed by the NRCS in conjunction with a watershed work plan. Standard NRCS methodology was used and is explained in TR-20 (Reference 24). The channelization completed in 1980 decreases the attenuation in flood peaks previously afforded by overbank storage. Therefore, a constant discharge was used from the outlet of the culvert under the BNRR to Salt Creek.

Peak discharge-drainage area relationships for each flooding source studied by detailed methods are shown in Table 2, "Summary of Discharges."

3.2   Hydraulic Analyses

Analyses of the hydraulic characteristics of flooding from the sources studied were carried out to provide estimates of the elevations of floods of the selected recurrence intervals. Users should be aware that flood elevations shown on the FIRM represent rounded whole-foot elevations and may not exactly reflect the elevations shown on the Flood Profiles or in the Floodway Data tables in the FIS report. Flood elevations shown on the FIRM are primarily intended for flood insurance rating purposes. For construction and/or floodplain management purposes, users are cautioned to use the flood elevation data presented in this FIS in conjunction with the data shown on the FIRM.

Cross-section data and topographic mapping for streams studied in detail in the City of Lincoln were determined by photogrammetric methods from aerial photographs taken in December 1978. The topographic mapping scale is 1:4,800, with a contour interval of 4 feet (Reference 31). Bridge geometry and cross sections were obtained by land survey. Additional data on Salt Creek bridges and levees were obtained from three USACE Design Memorandums: "Channel Improvement and Levees through Lincoln, Nebraska" (Reference 32); "Bridge Alterations through Lincoln, Nebraska, above Oak Creek" (Reference 33); and "Revised Plan of Improvements, Lincoln, Nebraska, and Vicinity" (Reference 34).

Cross-section data for all remaining streams studied by detailed methods were obtained by land survey methods between December 1978 and April 1979. Additional cross section data were taken from USGS quadrangle maps to extend cross sections (Reference 28). Bridge geometry and cross section data were taken concurrently with the above field surveys. Survey data and cross-section locations for Ash Hollow Creek were obtained from the NRCS and the City Engineer for the City of Waverly.

Roughness coefficients (Manning's "n" values) for each stream studied were assigned so that computed water-surface profiles would be consistent with stream-gage data, historic flood data, and other hydraulic studies. Where such information was not available, roughness coefficients were established from "Open-Channel Hydraulics" (Reference 35) and by field inspection. Table 3, "Manning's "n" Values," provides the ranges for roughness coefficients used for each stream studied by detailed methods.

The USACE HEC-2 computer program was used to determine water-surface profiles for the majority of the streams in this study (Reference 36). Starting water-surface elevations for Oak Creek and North Oak Creek were determined using coincident peaks analysis with Salt Creek (for Oak Creek) and Oak Creek (for North Oak Creek). Starting water-surface elevations for the remainder of the streams studied in detail for the City of Lincoln were

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Table 2. Summary of Discharges

Flooding Source and Location	Drainage Area (Square Miles)	Peak Discharges (Cubic Feet per Second)			
		10-Year	50-Year	100-Year	500-Year
Antelope Creek					
At mouth	7.4	3,600	6,600	8,200	10,100
At N Street	6.0	3,400	6,250	7,800	9,700
At A Street	4.2	3,200	6,000	7,300	9,400
Just upstream of 40th Street	2.1	2,100	3,800	4,700	6,000
Just upstream of 48th Street	1.2	1,300	2,400	3,000	3,800
Just upstream of 56th Street	0.1	110	200	250	300
At dam	0.0	0	0	0	0
At 70th Street	2.9	1,200	2,250	2,800	3,900
At Pioneers Boulevard	2.0	850	1,580	1,930	2,700
At 84th Street	1.1	540	1,000	1,230	1,700
Ash Hollow Ditch					
At mouth at Salt Creek	4.7	890	1,280	1,490	1,890
Beal Slough					
At mouth	12.9	2,650	4,950	6,200	8,700
At U.S. Highway 77	12.3	2,850	5,350	6,600	9,200
Just upstream of 27th Street	10.7	2,580	4,750	6,000	8,500
At 40th Street	6.6	1,960	3,600	4,500	6,300
At State Highway 2	5.1	1,750	3,250	4,000	5,600
At South 70th Street	1.8	790	1,480	1,800	2,600
Middle Branch Big Nemaha River					
0.25 mile upstream of State Highway 341	27	9,970	15,170	17,500	23,500
0.75 mile downstream of State Highway 341	30	10,870	16,760	19,355	26,500

Table 2. Summary of Discharges (Cont'd)

Flooding Source and Location	Drainage Area (Square Miles)	Peak Discharges (Cubic Feet per Second)			
		10-Year	50-Year	100-Year	500-Year
Cardwell Branch					
At mouth	7.7	830	1,550	1,900	2,700
Just downstream of unnamed tributary	4.8	1,000	2,100	2,700	3,700
Just upstream of unnamed tributary	1.5	270	500	630	850
At extraterritorial limits	1.0	240	450	570	770
Deadman's Run					
At mouth	9.3	4,160	7,750	9,660	12,700
At 38th Street (Station 8500)	9.3	3,750	6,990	8,710	11,400
Below 48th Street	6.9	3,670	6,850	8,530	11,100
Above 48th Street	5.7	3,110	5,790	7,210	9,350
At Cotner Boulevard	4.8	2,480	4,630	5,780	7,480
Below 66th Street	4.0	2,150	4,000	4,980	6,480
Above 66th Street	2.3	1,440	2,680	3,330	4,320
Below O Street	2.3	1,200	2,240	2,790	3,620
Below O Street	1.2	760	1,420	1,760	2,280
At A Street	1.1	590	1,090	1,360	1,770
Elk Creek					
At mouth	27.0	4,450	8,300	10,200	14,700
Just downstream of West Oak Creek	26.0	4,600	8,500	10,400	15,000
Just upstream of West Oak Creek	15.0	2,580	4,750	6,000	8,700
Haines Branch					
At mouth	53.0	4,350	8,100	10,100	15,400
Above 800 feet upstream of BNRR	45.0	4,450	8,400	10,400	15,400
At Lincoln extraterritorial limits	--[1]	4,800	5,100	11,000	16,400

[1]Data Not Available

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Table 2. Summary of Discharges (Cont'd)

Flooding Source and Location	Drainage Area (Square Miles)	Peak Discharges (Cubic Feet per Second)			
		10-Year	50-Year	100-Year	500-Year
Hickman Branch					
Just downstream of State Highway 477	53.4	8,250	14,500	17,500	26,500
Hickman Branch Tributary					
At mouth	1.7	1,170	2,000	2,500	4,000
Little Nemaha River					
Above State Highway 43	13.03	4,570	7,340	8,555	11,560
At eastern extraterritorial jurisdiction limits of Bennet	20.41	6,440	10,250	11,925	16,035
Unnamed Tributary to Little Nemaha River					
Above State Highway 43	5.21	1,725	2,755	3,210	4,345
Lynn Creek					
At mouth	4.1	1,960	3,600	4,500	6,200
At U.S. Highway 34	3.2	1,960	3,600	4,500	6,140
Middle Creek					
At mouth	55.0	5,200	9,900	11,900	16,300
At U.S. Highway 6	41.0	4,800	9,000	11,000	15,100
At Interstate 80	39.0	4,600	8,800	10,800	15,700
Just upstream of South Branch confluence	4.0	830	1,550	1,900	2,800
South Branch Middle Creek					
At mouth at Middle Creek	31	4,600	8,300	9,700	14,000
At U.S. Highway 6	23.4	3,900	7,000	8,200	11,900
At county limits (South 140th Street)	17.9	3,500	6,300	7,500	10,700

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Table 2. Summary of Discharges (Cont'd)

Flooding Source and Location	Drainage Area (Square Miles)	Peak Discharges (Cubic Feet per Second)			
		10-Year	50-Year	100-Year	500-Year
Oak Creek					
At mouth	169.0	7,800	14,300	17,900	23,000
At Interstate 80	160.0	7,550	13,900	17,500	23,000
Just upstream of Elk Creek confluence	120.0	4,300	8,100	10,000	16,100
About 200 feet downstream of West Waverly Road	115	4,750	8,900	11,100	17,700
At West Waverly Road	113	5,000	9,500	11,500	18,200
At West Bluffs Road	110	5,000	9,500	11,600	18,300
North Oak Creek					
At confluence with Oak Creek	95.5	5,600	10,400	12,500	19,400
At upstream limit of detailed study	94.5	6,200	11,200	13,400	20,500
At Agnew Road	88	7,200	12,500	14,900	22,500
Salt Creek					
About 5,000 feet downstream of North 148th Street	616	24,000	45,500	57,600	76,200
About 2,500 feet downstream of 98th Street	611.0	24,000	37,000	45,800	53,700
Just downstream of Stevens Creek confluence	588.0	25,000	38,500	47,900	55,800
Just upstream of Stevens Creek confluence	537.0	22,000	31,500	39,200	43,800
Just downstream of Little Salt Creek confluence	529.4	22,800	32,500	40,200	44,600
Just upstream of Little Salt Creek confluence	484.0	18,800	25,500	32,000	42,400
Just downstream of Deadman's Run confluence	477.8	20,700	25,300	31,600	43,800